THE MOVEMENTS OF THE EARTH[1]

IV.—*The Earth's Revolution*

It will be clear from what has gone before that the daily movement of the stars is an apparent one due to the real movement of the earth in an exactly opposite direction, and that the stars in the heavens appear to rise in the east and set in the west, because the earth rotates from west to east. And now comes this question: The period of twenty-four hours which is so familiar, and which is divided roughly into day and night, has apparently two perfectly different sides to it; for a certain period the stars are not seen at all in consequence of a body, which we call the sun, flooding the earth's atmosphere with its own tremendous light. Why should this be? In giving an answer to this question it is enough to say that the sun is a star so close to us, and so entirely outshining the other and more distant stars which are seen in the skies, that they seem to be things of a different order altogether. But they are not things of a different order, they are very much like our sun, and the different appearance is simply the result of the fact that the one is a star very near to us, whilst the others are suns inconceivably remote. In considering this apparent daily movement of the stars, and taking the sun into consideration, the fact is soon arrived at that the stars have another apparent movement differing somewhat from that one with which up to the present time we have alone been engaged. It has been said, and it is so obvious that it might almost have been left unsaid, that as a rule the stars are not seen when the sun is visible, so that the question whether the sun moves or appears to move among the stars must be attacked in a rather indirect manner. An observer on that part of the earth's surface directly under the sun sees it as at midday. Under these conditions the stars are of course not seen by him, but if he waited twelve sidereal hours, until that portion of the earth which he inhabited was opposite the sun's place, the stars would then be visible, and by noticing whether those seen by him each night were the same, he would be able to determine whether or not the sun moved or appeared to move among them. In one position of the sun it occupies that constellation of stars known as the Bull. These stars cannot then be seen, because the intense brilliancy of the sun puts them out, but with the sun in this position the group of stars known as the Scorpion is seen opposite at midnight. Then at a later period the sun gets into the constellation called the Crab, and we see at midnight no longer the Scorpion group but the group which is called the Goat. In this way it can be determined that the sun has an apparent movement among the stars, which is completed in a period which we call a year, at the end of which time the sun occupies the same position that it did a year previously, and the same group of stars is seen again in the south at midnight.

Not only, then, do the stars appear to make a complete revolution once a day, in consequence, as we have seen, of the earth's rotation, but once a year they also gradually change their apparent places, so that at the same hour each night different stars appear due south, thus indicating a movement of the sun among them.

The same difficulty that was met with before is again encountered here; is this movement of the sun among the stars a real or an apparent one? It is a question, however, which has been long since answered; and it can be very definitely stated, not only that the earth rotates on its axis in a period of twenty-four sidereal hours, but that it moves or revolves round the sun in a period which we call a year, and that it is this real movement which causes the apparent one of the sun among the stars. Let the reader take a top and spin it. Perhaps the top has a movement of progression as well as a movement of rotation, and it is in that way quite easy to see that the earth may rotate on its axis and revolve about the sun at one and the same time. And with a top of special construction its axis of rotation might be inclined so that its plane of rotation ceased to coincide with the plane of its motion of progression; still the two movements would go on, and in whatever position the top might be placed, its axis might be made to remain practically parallel to itself during its movements.

We may now, then, make the following statements:—*The earth revolves round the sun, and throughout the revolution the axis of rotation remains practically parallel to itself.* With regard to the latter part of this statement it may be added that if this were not so—if the axis of the earth were subject to perpetual change of direction—the declinations of the stars would also be subject to constant change.

The demonstration of this movement of the earth round the sun depends upon physical considerations in exactly the same way as does the demonstration of the earth's movement of rotation, and to these considerations attention must now be turned. It will be found that we have now to do with an entirely different branch of physics to that which we drew upon when seeking for a proof of the rotation. The utilisation of its principles for the purposes of astronomy is due to Dr. Bradley, a former Astronomer-Royal. In the year 1729 he made a series of observations of stars, expecting certain results to flow from them. Instead, however, of getting the results for which he had looked, his observations gave him some which differed entirely from his predicted ones, and which he failed to understand. For such a thing as this to happen is a piece of good fortune for the scientific investigator; it sets him thinking and working, and frequently leads him to the discovery of some hitherto unknown physical law. It set Dr. Bradley thinking and working. Curious as it may seem, the observation which led him to a complete understanding of this subject was what he observed one day when a boat at anchor near the shore at Greenwich began to get under weigh in a stiffish breeze. The little boat had one of those short pennants on its mast, and Dr. Bradley noticed that, as soon as the boat began to move, the direction of the wind, as indicated by the movements of this pennant, changed. Before proceeding to consider the bearing which this fact, seemingly remote from astronomy, has upon star work, it may be advisable to take one or two simple illustrations which will show what must have passed through Bradley's mind as the explanation of the strange unexpected movements of the stars was slowly growing within it. The first illustration is one due to Sir George Airy. Suppose that a vessel is passing a fort, and that a shot is fired from the fort at the moving vessel. The shot will travel in a straight line; but it is evident that since the ship is moving, if that shot really pierces both sides of the vessel, then a line joining the spot where the ball pierced the one side to the spot where it pierced the other side will not be square to the direction of the ship's motion. During the short time taken by the shot to pass from one side of the ship to the other, the vessel has moved through a certain small distance, and if the line joining the two shot-holes were alone considered, it might be inferred that the shot had come from a direction in advance of the true one. That is one illustration, the point of it being that the motion of the vessel seems to have given a new direction to the shot. Take another illustration, more familiar, and perhaps almost as clear. In this country frequent opportunities offer themselves of travelling in cabs or railway trains, with the rain falling on their closed windows. Every one must have noticed that at such times there is always a very curious slant in the apparent direction of the drops whilst the train or the cab is in motion; the rain seems to come from a point in front of us; we always seem to meet the rain. The fact is that a body in motion, and especially a body with the velocity of an express train, does not receive the rain under the same conditions as when it is at rest. The question of its velocity has to be taken into consideration. An experiment will show better what is meant.

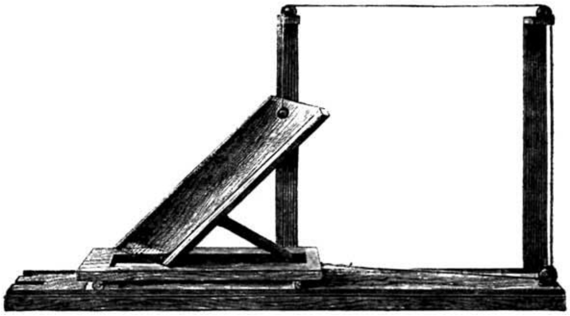

FIG. 35.—Model to illustrate the aberration of light. A square tube, with glass front and a slit along the centre of its upper side to allow the passage of a thread, is inclined at 45° and caused to run along a level track, while a weight suspended from a thread passing round three pulleys and attached at the other end to the front of the carriage is allowed to descend. In this figure the weight is at the commencement of its fall.

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[1] Continued from vol. xxix. p. 205.

Imagine a weight supported by a piece of thread; the moment that thread is cut the weight falls in a straight line to the ground. If it be desired, therefore, to receive the falling weight in a tube at rest under the weight, and to so receive it that it shall not touch the sides of the tube as it passes through, the tube must be held in an upright position. Take another step, and suppose now that it is a question of causing the weight to fall through the tube whilst the tube itself is travelling at a certain rate, say at the velocity of the falling weight. It is perfectly obvious that this cannot be done by holding the tube in a perpendicular position, the tube must be inclined, and the angle of its inclination will vary with the varying relative velocities of tube and weight. The more quickly the weight falls the less inclined must the tube be to receive it. This not only supplies the explanation of the slant of the rain on the windows of the railway carriage, but it explains what is very much more important from an astronomical point of view. Consider Fig. 37 for a moment. Here AB represents the path of anything falling, and *a* CB the angle of the tube destined to receive it. It may be called the angle of slant, but the point is not that we give it any particular name, but that its relation to the velocity of fall is a very fixed and definite one. Accept it as such, and then connect it, not with the falling weight or with the slant of the rain, but with the velocity of the light coming to the earth from any star in the heavens, and the velocity of the earth in its orbit round the sun.

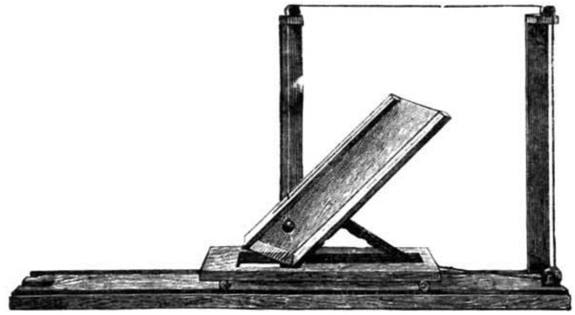

FIG. 36.—Same apparatus as preceding, but with the weight near the end of its fall.

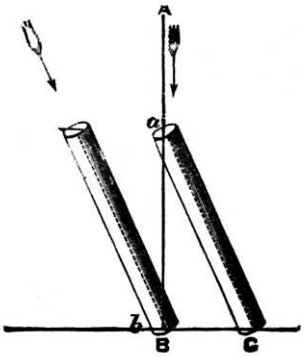

FIG. 37.

It may be said that two assumptions are here made, first that light has a velocity, and secondly that the earth does move round the sun. Consider, then, the first of these, the question of the velocity of light. In our day, with all the experimental methods d niceties which the labours of those who have gone before have placed at our disposal, this question of the velocity of light can be answered by what may be called a laboratory experiment. The first real attempt to answer the question was made some years ago by a Frenchman, M. Fizeau. His method of observation was a beautifully simple one, and has turned out to be highly satisfactory in its results. All the essential parts of his apparatus are shown in Fig. 38. Light from a lamp was made to pass through a system of lenses and was brought to a focus after reflection from the front surface of a piece of plain glass. The light was then grasped by an object-glass and sent out in a parallel beam to a station distant about five miles. There it fell on another object-glass, which again brought it to a focus on a mirror at the end of this second telescope. Then having got the light to the second mirror, it was reflected on its path back again. When the reflected light returned, part of it was allowed to go through the plain glass mirror to the eyepiece seen at the end of the telescope in Fig. 38. At the point where the rays crossed in the first telescope there was interposed the edge of a cogged wheel, to which a great velocity of rotation could be imparted by clockwork, and through the intervals between the teeth of which the light had to pass. Suppose first that the wheel is at rest. The lamp is lighted, and looking through the cogs of the wheel the observer sees the image of the lamp reflected back to him as a star of light from that distant mirror by means of the arrangement to which reference has been made.

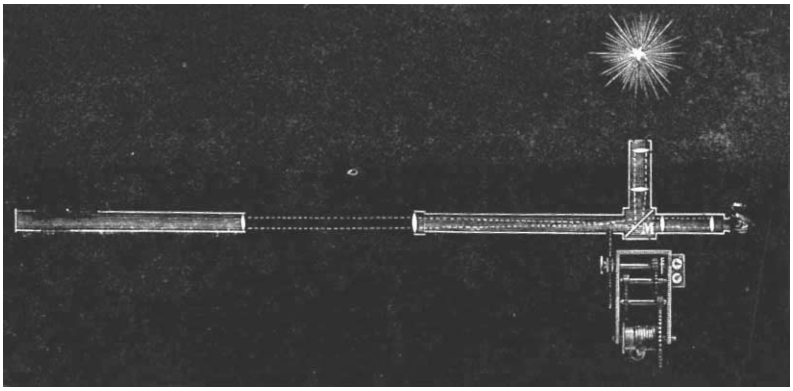

FIG. 38.—Fizeau's mode of determining the velocity of light.

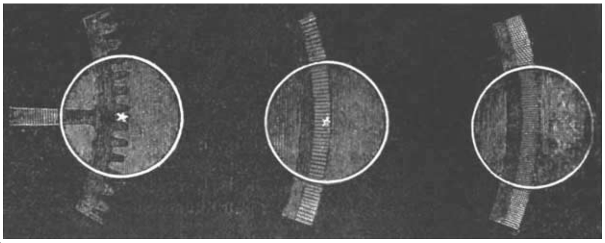

FIG. 39.—Fizeau's velocity of light apparatus. Appearance when the toothed wheel is at rest, when it is in slow motion, and when its rotation is so rapid as to cause complete extinction of the light.

Assume now that light occupies no time in travelling from the lamp to the first mirror, through the first telescope, across the space between the two telescopes, and back again after its reflection by the second mirror. Assume, in fact, that the velocity of light is infinite, then it is perfectly clear that an observer would keep on seeing that star of light whether the wheel remained at rest or were put in motion. But now assume that light does take a certain very small time to make the journey spoken of, and that the wheel can be turned with just such a velocity that when the light reaches it on its return it will meet, not an opening, but one of the cogs. Then the light would not be visible; it would find itself a cog behind, so that, if light travels very fast indeed and the wheel is made to travel with a great and known velocity and the relation existing between the velocities be known, the velocity of light can be measured in this way. That is the way in which Fizeau measured it, and he gave the velocity as being 190,000 miles per second.

It may be thought perhaps that this being the first attempt in a matter of this kind it was not very worthy of credit; but the similarity of the results which have been obtained in all such experiments proves that they are all very worthy of credit, and that this velocity must be accepted as established within narrow limits.

We come now to Foucault, the man to whose genius science owes the experimental proof of the earth's rotation, to which reference has already been made. He also attacked this question of the velocity of light. Going to work in quite a different way from Fizeau, he succeeded in enriching science with a method quite as reliable in its operation and as accurate in its results.

A pencil of light coming from a slit at S (see Fig. 40) impinges upon the plane mirror R, which is capable of turning round a vertical axis. This mirror reflects the light falling on its surface, and the action of the lens, L, causes an image to be formed on the surface of the concave mirror, M, the centre of which coincides with the axis at R. This concave mirror reflects the image backwards on its path to the slit. Foucault's arrangement, as has been said, was to have the mirror, R, made to rotate. If, therefore, R be turned about its axis while the light from the slit, S, is falling upon its surface, for so long as the light falls on the lens so long will the image of the slit be formed on the surface of the distant mirror. Similarly for so long as the reflected image falls upon the lens, so long will the image be reflected back to the slit. Now if the mirror were made to rotate rapidly, and light were infinite in its velocity, then once during each revolution of the mirror at one particular angle the light would be reflected back to the slit; but assume that light takes some very small fraction of time to travel over the space between the mirrors, it will be observed that the image will not be reflected back to the slit but will suffer a deflection in one direction or the other according as the mirror turns from left to right or from right to left, and, the velocity of the rotating mirror being known, the amount of this displacement will enable the velocity of light to be determined.

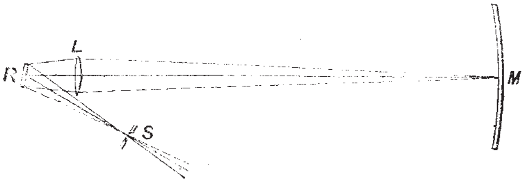

FIG. 40.—Foucault's arrangement for determining the velocity of light.

With two such different methods it might be supposed that the results obtained were very different. Not so, however; the velocity obtained by Fizeau was, as I have said, 190,000 miles per second, that by Foucault 185,000 per second.

It so happens that both these methods have been gone over quite recently, Fizeau's method by another Frenchman, M. Cornu, and Foucault's by Mr. Michelson, an officer in the American navy.

Mr. Michelson modified Foucault's method somewhat, the fault in which was that the displacement obtained was so extremely small, being but the fraction of a millimetre; and when it is remembered that the image is always more or less indistinct on account of atmospheric conditions and imperfection in the lenses and mirrors employed, it will be seen that it was difficult for Foucault to attain to any very great accuracy. Mr. Michelson therefore used an apparatus which would give him a greater deflection than that obtained by Foucault. As before, S (Fig. 41) was the slit, R the rotating mirror in the principal focus of the lens, but the distant mirror, instead of being concave, was a plane one, and the lens one of great focal length, for a reason that will appear immediately. This lens, in consequence of the smallness of its diameter in comparison with its great focal length, was not entirely convenient. In order that the displacement should be great, it is necessary that the distance between R and M, the distance from the revolving mirror to the slit, and the speed of rotation should be the greatest possible.

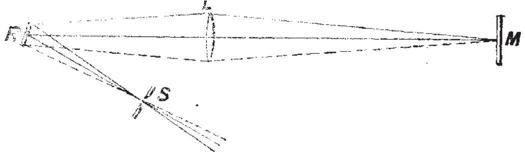

FIG. 41.—Michelson's variation of Foucault's experiment.

Unfortunately, the second condition clashes with the first,[1] for the distance from the revolving mirror to the slit, or the "radius" is the difference between the distances of principal and conjugate focus for the distant mirror M, and the greater the distance the smaller the radius. Two methods were employed by Mr. Michelson in overcoming this difficulty: first, he had his lens of great focal length, 150 feet, and he placed the revolving mirror, not at the principal focus, but fifteen feet within it. He thus managed to get a distance between the mirrors of 2000 feet with a radius of thirty feet, and his mirror made 256 revolutions per second. He then obtained a deflection of 133 millimetres, that being about 200 times greater than the deflection obtained by Foucault. This deflection he measured to within three or four hundredths of a millimetre in each observation.

Mr. Michelson's experiments were made along an almost level stretch of sea wall at the Naval Academy.

We are therefore justified in saying, as the result of these experiments of Fizeau and Cornu, Foucault and Michelson, that light has a velocity of some 186,000 miles per second.

If that be so, then, if the statement that the earth revolves about the sun be true, this must follow. In Fig. 42 *a*, *b*, *c*, *d* represent the earth in different parts of its orbit around the sun; the contention is that if there be this revolution of the earth round the sun, and if light really travels with anything short of an infinite velocity, then the position of a star must change, for the reason that the telescope of the astronomer must always be pointed in advance of the star to catch its light in the same way that to catch the falling weight we had to incline the tube in the direction of its motion.

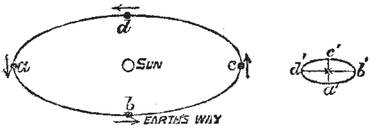

FIG. 42.—Annual change of a star's position, due to aberration: *a b c d*, the earth, in different parts of its orbit: *a' b' c' d'*, the corresponding aberration places of the star, varying from the true place in the direction of the earth's motion at the time.

When any observation is made on any star in the heavens, the telescope of the astronomer must therefore be pointed in advance of the star to catch its light, and taking, as in the diagram, four different points in the earth's orbit, it is obvious that the telescope at these four different points must be pointed in four different directions with regard to the star. For instance, if we take a point at *c*, where the earth is travelling in the direction of the arrow, and the point at which the star would be seen if the earth were at rest, or the velocity of light were infinite, be indicated by the star in the figure, *c'* is the direction in which the star would be seen, and in which the astronomer's telescope must be pointed to catch its light. Similarly with the earth at *d* the telescope must be pointed to *d'*, and so with the earth at *a* we must have it pointing towards *a'*. It was this strange anomaly which puzzled Dr. Bradley in the year 1729.

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[1] For full details of Michelson's experiments see NATURE, vol. xxi. p. 94 *et seq*

He noticed that the stars moved in ellipses every year round a mean point. This fact of aberration, then, is a real thing. It has been said that the angle at which the tube had to be inclined to receive the weight depended upon their respective velocities, that the faster the tube travelled, the greater must be its inclination, and therefore the greater the angle the greater the earth's velocity with reference to the velocity of light. In the case of the majority of the stars what we get is an ellipse, and in an ellipse we have certain differences which have to be taken into account, the last difference of all being that an infinitely elongated ellipse is a straight line, and it is found that from one particular point of the heavens where, in consequence of this aberrational motion, the orbits of the stars round their mean places are almost circular, we at last get to a point where the motion is simply an oscillation of the star backwards and forwards to and from its mean place; we are dealing, in fact, with that form of the ellipse when it is in the form of a straight line. When we deal with an ellipse we no longer talk of the radius, but of the semi-axis major, which is half the greatest length. The angle of aberration of which I have spoken only amounts to 20″·4451, but though small, it is quite enough to prove that the earth does revolve, and that consequently the sun is the centre of the system to which the earth belongs. Now in order to show the importance of physical inquiry in this matter, there is another statement which must be made. If we consider this aberration question fully, we find in it what is perhaps the most perfect way of determining the distance of the sun from the earth, and it will be seen that it is perfectly simple, so simple in fact, that the wonder is that more attention has not been given to it in our text-books. We have first the fact that the inclination of the tube depends upon the relative velocities of the tube and falling body; in the case of light it will of course depend upon the relative velocities of the earth in its orbit and light radiating from a star. Knowing this latter to be somewhere about 186,000 miles per second, and the aberration angle to be 20″ and something, we can get the relation of the earth's motion to the velocity of light, and it comes out to be about 1 to 10,089.

Now we know that the earth completes a revolution round the sun in 365¼ days. If it travelled with the velocity of light it would complete a revolution in 52m. 8·5s.

Again, we may say, and this is only a rough statement, that the radius of a circle is 1/6 of its circumference, so that if it took the earth fifty-two minutes to go round its circumference, or, as we call it, its orbit, it would take 1/6 of that time to go along the radius if it travelled with the velocity of light; it would therefore take 8m. 18s. But this radius is the distance of the earth from the sun, and having this time 8m. 18s., we have only to multiply the velocity of light[1] per second, by that, and we get 92,628,000 miles as the distance of the earth from the sun.

J. NORMAN LOCKYER

(*To be continued.*)

THE ROYAL COMMISSION ON TECHNICAL INSTRUCTION

WE have just received from the Commission the two volumes of their second Report on Technical Education. We give this week the Recommendations with which the Commissioners conclude their Report:—

Having carefully considered what is desirable and practicable in regard to the general and technical instruction of the various classes engaged in industrial pursuits in this country, we humbly offer the following recommendations, which require the intervention of the Legislature or of public departments:—

I. As to public elementary schools:

(*a*) That rudimentary drawing be incorporated with writing as a single elementary subject, and that instruction in elementary drawing be continued throughout the standards. That the inspectors of the Education Department, Whitehall, be responsible for the instruction in drawing. That drawing from casts and models be required as part of the work, and that modelling be encouraged by grant.

(*b*) That there be only two class subjects, instead of three, in the lower division of elementary schools, and that the object lessons for teaching elementary science shall include the subject of geography.

(*c*) That, after reasonable notice, a school shall not be deemed to be provided with proper "apparatus of elementary instruction" under Article 115 of the Code, unless it have a proper supply of casts and models for drawing.

(*d*) That proficiency in the use of tools for working in wood and iron be paid for as a "specific subject," arrangements being made for the work being done, so far as practicable, out of school hours. That special grants be made to schools in aid of collections of natural objects, casts, drawings, &c., suitable for school museums.

(*e*) That in rural schools instruction in the principles and facts of agriculture, after suitable introductory object lessons, shall be made obligatory in the upper standards.

(*f*) That the provision at present confined to Scotland, which prescribes that children under the age of fourteen shall not be allowed to work as full-timers in factories and workshops unless they have passed in the Fifth Standard, be extended to England and Wales.

II. As to classes under the Science and Art Department, and grants by the Department:

(*a*) That School Boards have power to establish, conduct, and contribute to the maintenance of classes for young persons and adults (being artisans) under the Science and Art Department. That in localities having no School Board the local authority have analogous powers.

(*b*) That the Science and Art Department shall arrange that the instruction in those science subjects which admit of it shall be of a more practical character than it is at present, especially in the "honours" stage; that payment on results be increased in the advanced stages of all subjects, at least to the level of those now made for practical chemistry and metallurgy, and that greater encouragement be given to grouping.

(*c*) That the examinations in agriculture be made to have a more practical bearing.

(*d*) That metallurgy, if it be retained, be divided into groups, as (1) the precious metals, (2) those extracted from metalliferous mines, as copper, tin, lead, &c., (3) iron and steel. That mining be similarly divided into (1) coal and (2) metalliferous mining.

(*e*) That the inspection of science classes by the Science and Art Department, with a view to ascertain the efficiency of the instruction, and of the apparatus and laboratories, be made more effective, with the assistance, where necessary, of local sub-inspectors.

(*f*) That it shall not be a requirement of the Science and Art Department that payment of fees be demanded from artisans for instruction in the science and art classes.

(*g*) That in the awards for industrial design more attention be paid by the Department, than is the case at present, to the applicability of the design to the material in which it is to be executed, and that special grants be made for the actual execution of designs under proper safeguards.

(*h*) That the limits of the building grants, under the Science and Art Department, to 500*l*. each for schools of Art and of Science should be abolished, and the conditions attached to them be revised.

(*i*) That, in addition to the loan of circulating collections and the grant of art reproductions at reduced cost, contributions be made to provincial industrial museums of original examples tending to advance the industries of the district in which such museums are situated.

III. Training Colleges for elementary teachers:

(*a*) That the teaching of science and art in Training-Colleges, and its inspection by the Science and Art Department, be made efficient, and that arrangements be made for giving to selected students in those Colleges greater facilities and inducements for the study of art and science in the National Art Training School and the Normal School of Science at South Kensington, the Royal College of Science for Ireland, and other institutions of a similar class approved of by the Government.

IV. Secondary and technical instruction:

(*a*) That steps be taken to accelerate the application of ancient endowments, under amended schemes, to secondary and technical instruction.

(*b*) That provision be made by the Charity Commissioners for the establishment, in suitable localities, of schools, or departments of schools, in which the study of natural science, drawing, mathematics, and modern languages, shall take the place of Latin and Greek.

(*c*) That local authorities be empowered, if they think fit, to establish, maintain, and contribute to the establishment and

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[1] The exact value is 186,380 miles according to Michelson, with a possible error of thirty-three miles.